1.3 Cells from Cells

Key Terms
cell division
mitosis
cytokinesis
DNA replication
prophase
metaphase
anaphase
telophase
cell plate

There are tens of thousands of different proteins in your body, and the types of proteins you have are determined by your genes. If a gene is missing or damaged, the protein it codes for may be missing or non-functioning. Thus, all 46 chromosomes you see in **Figure 1.18** are important.

Cell Reproduction

Cell reproduction is the process by which new cells are formed. An important difference between cell reproduction and the reproduction of a multicellular organism (one with a body consisting of many cells), however, is the number of "parents" involved. As you can see in **Figure 1.19**, when body cells and most single-celled organisms reproduce, there is only one parent: one cell divides to produce two new cells, which are called *daughter cells*. The two daughter cells are identical to each other and to their parent cell, at least in the genes they contain.

In sexual reproduction, two parents mate and the offspring receive half of their genes from each parent (one chromosome from each pair of chromosomes). Therefore, although offspring share genetic material and may look alike, they are not exactly the same. For example, not all of the kittens in a litter look the same. Each kitten receives half of its genes from each parent, but does not get exactly the same combination of genes as other kittens in the litter.

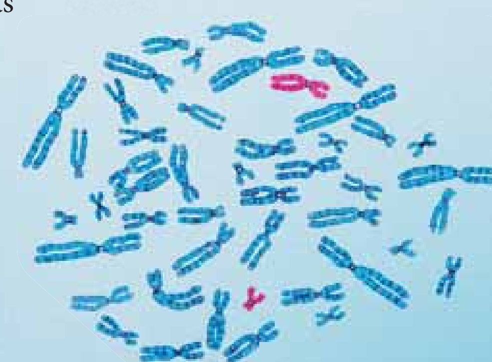


Figure 1.18 This karyotype shows the 46 chromosomes (magnified 1000 times) present in the nucleus of every cell in the body of a male human.

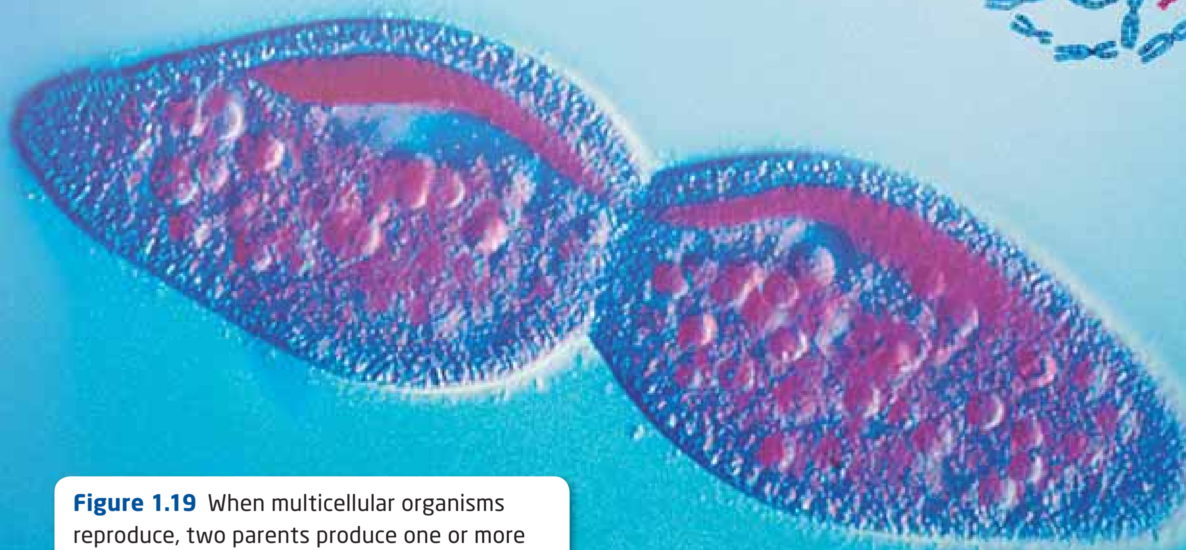


Figure 1.19 When multicellular organisms reproduce, two parents produce one or more offspring. When single-celled organisms like this *Paramecium* reproduce, however, one parent cell divides, resulting in two offspring.

cell division the process by which a parent cell divides into two daughter cells

Cell Division

The *Paramecium* shown in **Figure 1.19** has reproduced by dividing in two. In other words, it has undergone the process of **cell division**. For single-celled organisms, cell division is the main process by which individuals reproduce, and the population gets larger. For multicellular organisms, cell division is the process by which a fertilized egg (a single cell) becomes, eventually, an adult with millions of cells.

In multicellular organisms, cell division is also the process by which you replace lost or damaged cells, as you can see in **Figure 1.20**.

Figure 1.20 When you cut your skin, blood flows to the area until a scab forms. This scab restores the skin's continuity, preventing bacteria from entering the body. Then the skin cells underneath can undergo cell division to produce new cells that fill in the gap. Once the skin layer is restored, the scab falls off.

The Cell Membrane and Diffusion

Cells also divide when they grow too large to perform efficiently the functions necessary for their survival. The cell membrane plays a significant role in these functions. For example, when you eat food, it gets broken down into smaller and smaller molecules by your digestive system. These molecules—as well as the oxygen molecules in the air you inhale—then get delivered to every cell in your body. Once there, these substances must cross the cell membrane to get inside the cell, where they are needed. The cell's waste materials must also cross this membrane to exit the cell.

The cell membrane is, therefore, a barrier through which everything must pass on its way into or out of the cell. Much of this passage of materials occurs through the process of *diffusion*. Diffusion is the movement of molecules from areas where there are higher concentrations to areas where there are lower concentrations. Water crosses through the process of *osmosis*.

Moving from High Concentrations to Low Concentrations

Like the membrane in the beaker shown in **Figure 1.21**, the cell membrane is permeable to certain substances; that is, these substances can cross the membrane. Materials that the cell needs (such as oxygen) diffuse across the membrane from outside the cell—where they are more concentrated—to the inside—where they are less concentrated. A cell membrane is referred to as selectively permeable because not all materials can cross it; some are kept out—or in.

Study Toolkit

Visualizing When reading the text on this page, visualizing how molecules cross the cell membrane can help you understand and remember the process.

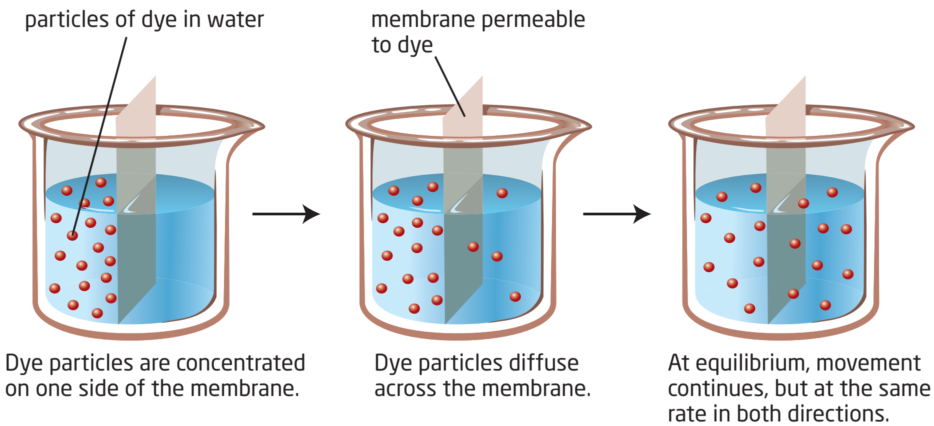
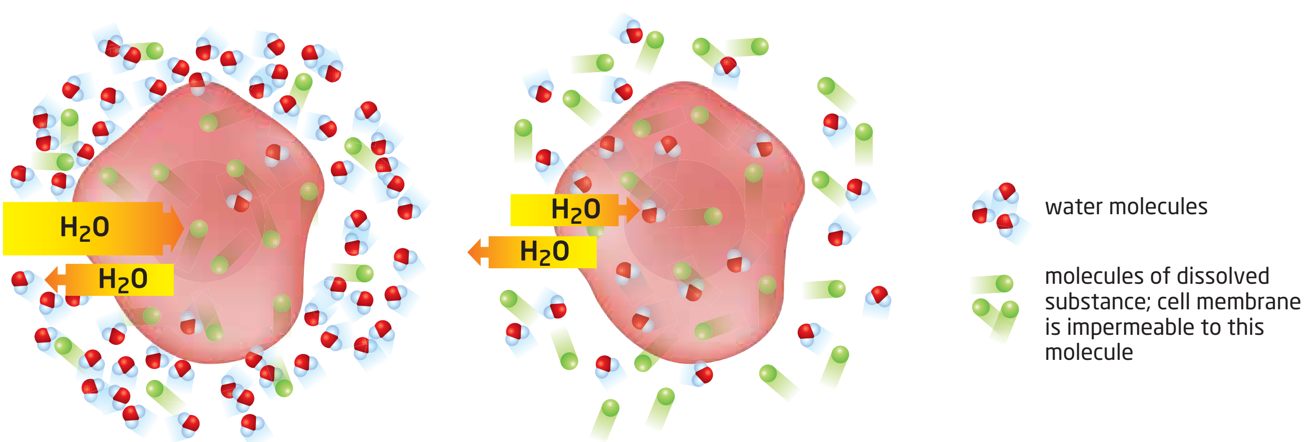


Figure 1.21 Diffusion occurs through a selectively permeable membrane. Dye particles diffuse from areas of high concentration to areas of low concentration until they reach a point of equilibrium.

Most cells are surrounded by solutions that contain water and dissolved nutrients and gases. Like other molecules, water moves from areas of greater concentration to areas of lesser concentration. In **Figure 1.22**, you can see how osmosis occurs over a cell membrane to equalize the number of water molecules inside and outside the cell.



A There is a greater concentration of the dissolved substance inside the cell than outside the cell.

B Water moves by osmosis into the cell until the concentration is the same outside and inside.

Figure 1.22 In **A**, you can see that the dissolved substance is more concentrated inside than outside the cell. It cannot diffuse through the cell membrane. However, water is more concentrated outside than inside. In **B**, you can see that water passes through the membrane until the concentration of water molecules is the same on both sides of the membrane.

Growing Cells

The surface of the cell must be big enough to allow for the entry of all of the oxygen and nutrients needed by the cell's organelles, nucleus, and cytosol. As cells use these nutrients, they produce more organelles and cytosol and thus get bigger. As a result, their volume increases. And, with more organelles doing their jobs, the cell's need for supplies and its production of wastes increase.

Limiting Cell Size

Every cell faces the problem of needing enough surface area to service its volume. As something gets larger, the ratio of its surface area to its volume decreases. In other words, there is less surface area per unit of volume in a large organism than in a small organism. As suggested by **Figure 1.23**, a cell cannot get too big, or it will not have enough surface area for the passage of all the nutrients it needs and the wastes it produces. Therefore, when a cell reaches a certain size, it must divide to produce smaller cells. Each of these smaller cells will then have enough surface area to suit its needs.

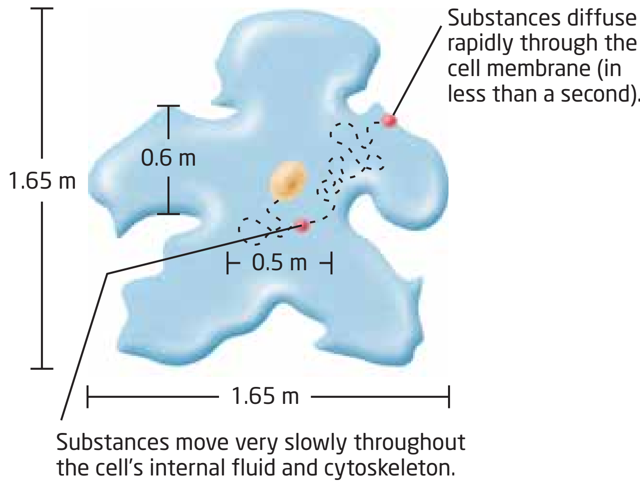


Figure 1.23 If an amoeba were as big as a human, critical substances, such as oxygen, would take years to get through the cell's cytoplasm to reach the centre of the cell. This would be far too long. In the meantime, the nucleus and other organelles would not receive the nutrients they need to function.

Learning Check

1. Using **Figures 1.21** and **1.22**, describe in your own words how substances cross the cell membrane. Use the term *concentration* in your answer.
2. When a cell divides to produce daughter cells, how similar are the daughters to the parent?
3. Why do the cells of multicellular organisms divide?
4. Do you have to worry about seeing a headline like "Giant *Paramecium* Threatens City"? Explain your answer.

Can a Cell Just Divide Down the Middle?

Is dividing a cell as easy as cutting an apple in half? What would happen if the nucleus were not right in the middle of the cell? Even if it were, would it work just to divide the total number of chromosomes in the nucleus in half? The contents of a cell, particularly its nucleus, are complicated. Each cell, therefore, has to take an organized approach to cell division—it cannot just break in two.

The nucleus contains the DNA, which is so important that the nucleus has its own multi-step division process, called **mitosis**. The cytoplasm divides by a different process, called **cytokinesis**.

mitosis the process by which the duplicated contents of the cell's nucleus divide into two equal parts

cytokinesis following mitosis, the separation of the two nuclei and cell contents into two daughter cells

Getting Ready for Mitosis

Recall that DNA is divided into segments called genes, each of which provides the instructions for making a different protein. Your body needs all of these proteins at one time or another—each plays a role in making up the structure of, or ensuring the proper functioning of, your body's many parts. Thus, every cell needs to have *all* the genes required to make these proteins. Although not every cell will end up making every protein, each starts out with the *potential* to do so.

Therefore, the parent cell cannot just divide its chromosomes equally between its two daughter cells when it divides. If this happened, each daughter cell would only have half the number of chromosomes its parent had and would be missing vital genes. In the case of human cells, each daughter cell produced through cell division needs a copy of all 46 chromosomes from its parent cell.

Study Toolkit

Word Families Creating a graphic organizer for words in this section that include the word part *phase* could help you understand and remember each word's definition.

DNA Replication

A parent cell therefore makes a copy of every chromosome before it divides. It can then give one copy to each of the daughter cells. This copying process is called **DNA replication**. During replication, each chromosome is duplicated, although the two copies remain attached to each other, as shown in **Figure 1.24**.

DNA replication the process by which DNA is copied, creating sister chromatids joined at the centromere

Until the cell gets ready to divide, chromosomes are normally more like very long, loose threads. Each "thread" is actually a tightly twisted strand of DNA—the spiral "ladder" you saw in **Figure 1.9**. The chromosomes take on the thick, bulging look you see in **Figure 1.24** just before the cell gets ready to divide. If you look closely at **Figure 1.24A**, you can see that each chromatid is composed of tightly bunched, threadlike material.

DNA replication is very precise. When copying errors occur, they are usually detected and fixed by special "proofreading" and repair proteins. At roughly the same time the DNA is replicated, an organelle called the *centrosome* also doubles, so that the cell has two copies. The centrosomes help to organize the tubules that make up the cytoskeleton. They play an important role in cell division, as you will see in the next section.

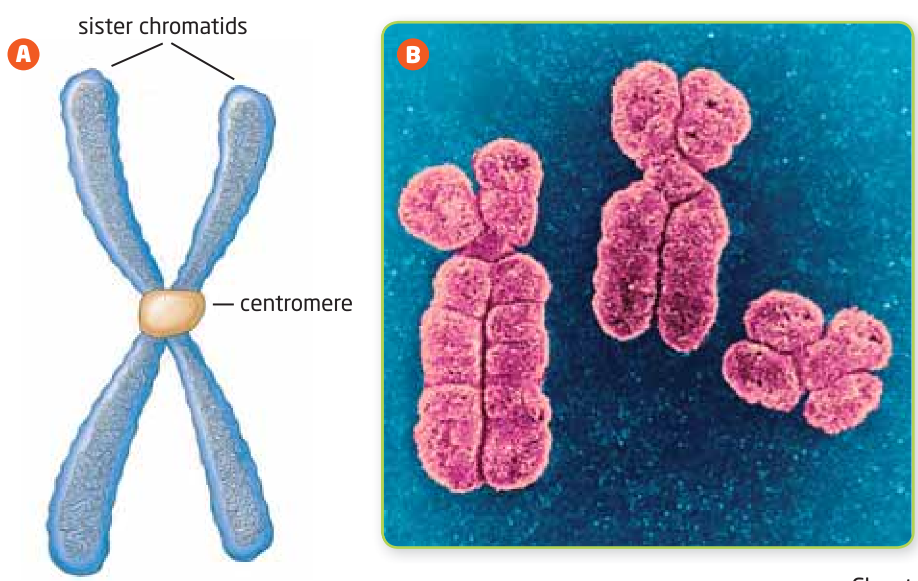


Figure 1.24 During DNA replication, each chromosome is copied to produce two sister chromatids, attached at the centromere. The two sister chromatids shown in **A** are still one chromosome–but a replicated chromosome. In **B**, you can see a human chromosome, magnified 6100 times, that is ready to undergo mitosis.

The First Stage of Cell Division: Mitosis

Although some are longer and some are shorter, the average strand of human DNA is about 5 cm long. Yet 46 chromosomes can fit in the nucleus of a microscopic cell. This is only possible because each chromosome is incredibly thin. The diameter of each DNA molecule is just 2 nanometres (0.000 002 mm), so small that it can only be seen with an electron microscope. For most of a cell's life, its DNA is virtually invisible. This changes when the cell starts to divide through the process of mitosis, shown in **Figure 1.25**.

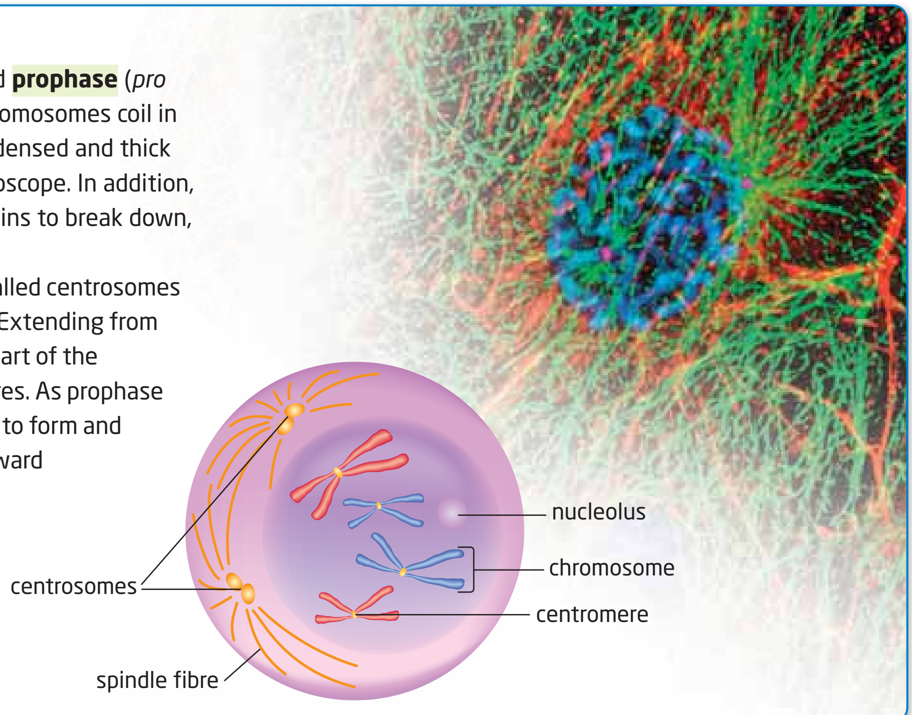
Figure 1.25 The phases of mitosis in a typical animal cell are shown on pages 34 and 35. A micrograph of a cell in the process of mitosis is shown beside the diagram of the same phase.

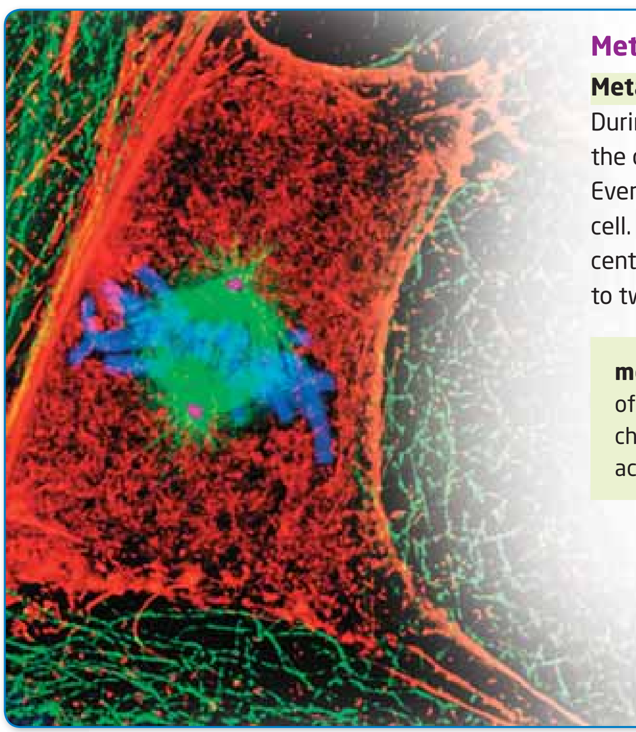
Prophase

During the first phase of mitosis, called **prophase** (*pro* is Latin for "before"), the replicated chromosomes coil in various ways until they are finally condensed and thick enough to be visible using a light microscope. In addition, the membrane around the nucleus begins to break down, and the nucleolus disappears.

At the same time, two organelles called centrosomes head toward opposite ends of the cell. Extending from the centrosomes, thread-like tubules, part of the cytoskeleton, begin to form spindle fibres. As prophase progresses, the spindle fibres continue to form and extend away from the centrosomes toward the centromeres on each chromosome.

prophase the phase of mitosis in which sister chromatids condense and the chromosomes become visible

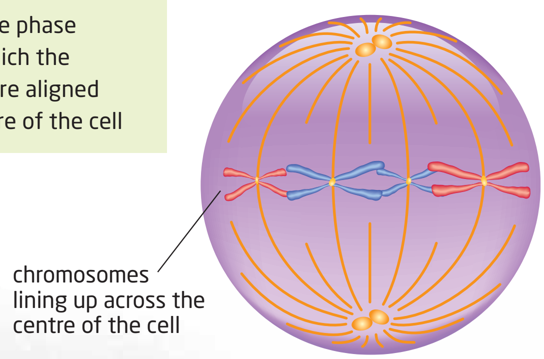




Metaphase

Metaphase (*meta* is Latin for "mid") is the longest phase in mitosis. During this phase, the centrosomes reach the opposite ends of the cell and the chromosomes move toward the middle of the cell. Eventually, the chromosomes all line up along the centre of the cell. By this point, the spindle fibres stretch all the way from the centrosomes to the centromeres. Each centromere becomes attached to two spindle fibres–one from each end of the cell.

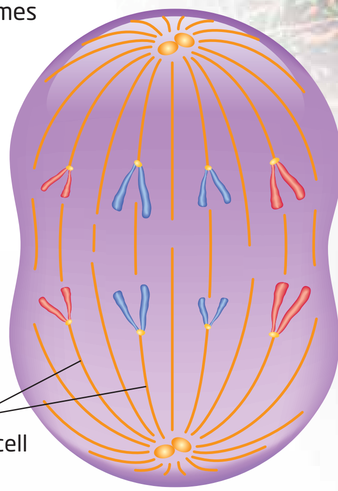
metaphase the phase of mitosis in which the chromosomes are aligned across the centre of the cell

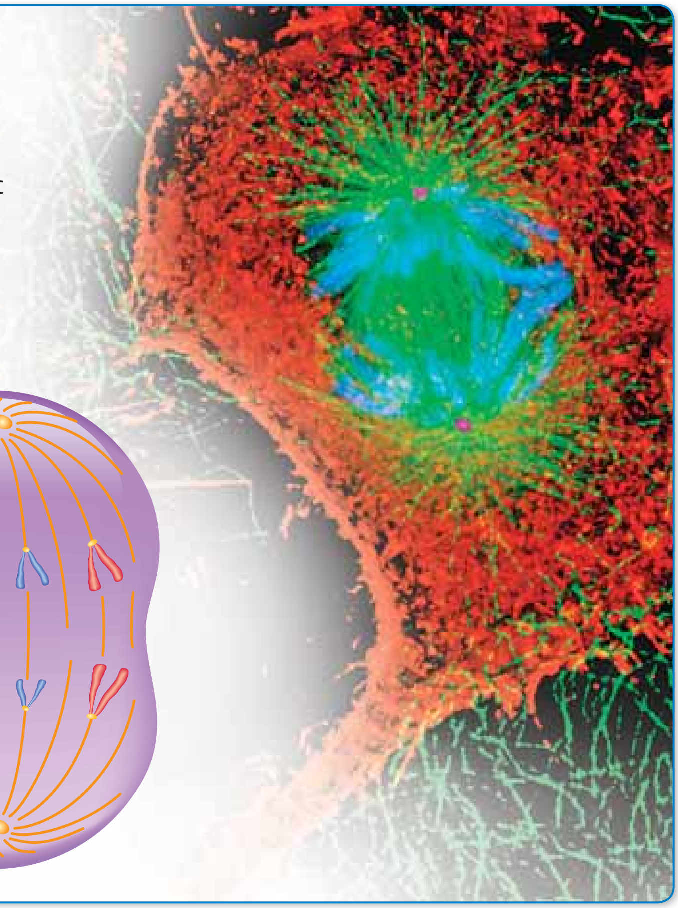


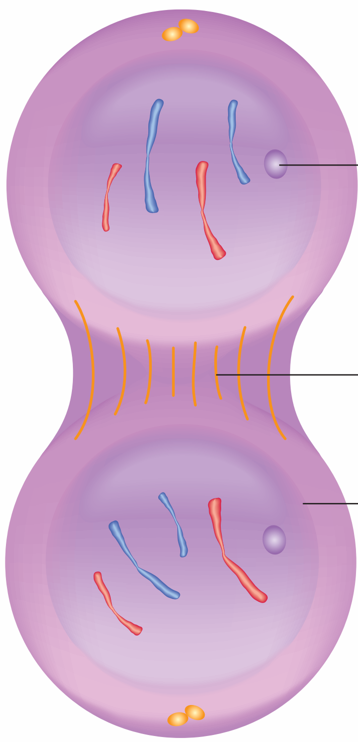
Anaphase

The next phase of mitosis, called anaphase (*ana* is Latin for "back"), is one of the shortest. In **anaphase**, the proteins holding the two chromatids together at the centromere break apart. The spindle fibres had been stretched like elastic bands between the chromosomes at the middle of the cell and the centrosomes at the opposite ends of the cell. Now the spindle fibres retract, each pulling a chromatid toward one end of the cell. Once the chromatids separate, each becomes a chromosome in its own right. At this point, the cell has twice as many chromosomes as usual.

anaphase the phase of mitosis in which the centromere splits apart and the chromatids are pulled to opposite sides of the cell by the spindle fibres



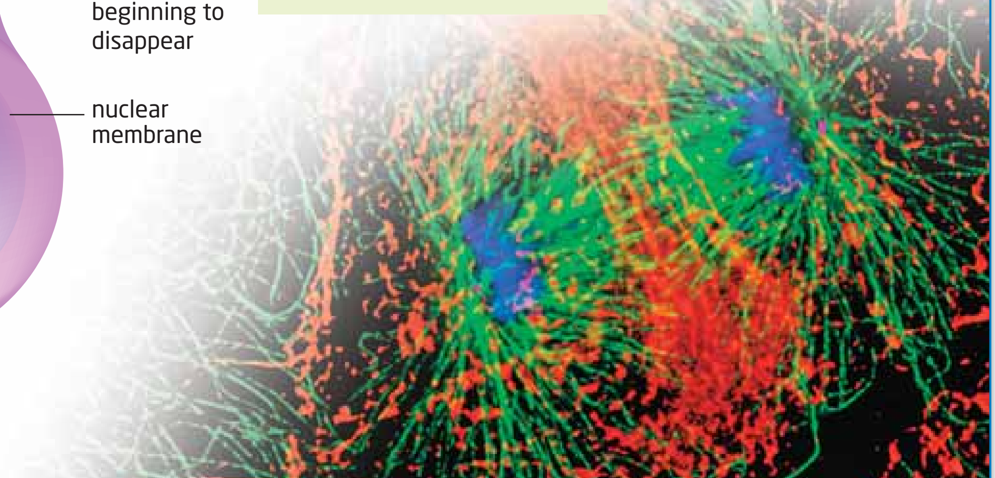




Telophase

During **telophase** (*telos* means "end"), the spindle fibres start to disappear. Membranes form around two new daughter nuclei, one at each end of the cell. Within each nucleus, a nucleolus appears, and the chromosomes become less coiled and harder to see. Mitosis, the division of one nucleus into two identical nuclei, is now complete. The rest of the cell is ready to divide.

telophase the phase of mitosis in which two daughter nuclei are formed



Mitosis Is Continuous

Go to **scienceontario** to find out more

Scientists—and students—use various strategies to make complicated ideas and processes easier to understand. One such strategy is to describe the process of mitosis as if it consists of a set of separate steps, as described on the previous pages. In reality, mitosis is continuous—there are no breaks between phases.

Activity 1-3

Modelling Mitosis

Understanding the process of mitosis can be easier if you make a model of it. What kinds of materials would best model the various parts of a cell during mitosis?

Safety Precaution

- Use caution when working with scissors.

As you choose your materials, be prepared to give a rationale for your selections.

Materials

- coloured paper
- poster paper
- markers
- various construction materials, such as toothpicks, string, twist-ties, paper clips, pipe cleaners, tongue depressors, several colours of yarn, elastic bands, and thread
- glue
- scissors

Procedure

1. Your teacher will assign you one phase of mitosis. Make a model of this phase using some of the supplied materials. Use four chromosomes in your model.
2. When finished, arrange your class's models in the order in which mitosis occurs.

Questions

1. Compare the various models, and discuss why students may have chosen different materials to represent the same structures.
2. In which phases is the nucleus visible?
3. How many cells does a dividing cell form?

Suggested Investigation

Inquiry Investigation 1-B, Mitosis in Plant and Animal Cells, on page 48

Learning Check

5. What does a cell do to prepare for cell division?
6. What structures ensure that each of the sister chromatids becomes part of a different daughter cell?
7. Using **Figure 1.25** as a model, sketch each phase of mitosis in your notebook. Include point-form notes that explain each phase.
8. Which cells of the human body do you think undergo mitosis more frequently than other cells? Why?

The Second Stage in Cell Division: Cytokinesis

The division of the rest of the cell—the cytosol and organelles—usually begins before telophase is complete. **Figures 1.26** and **1.27** show the process for animals and plants.

Cytokinesis in Animal Cells

In animal cells, a ring of specialized proteins around the middle of the cell starts to contract. Like pulling the drawstrings on a bag, this contraction pinches the cell membrane until the parent cell is divided into two parts. Each daughter cell has a complete set of chromosomes in a nucleus and its own share of cytosol and organelles.

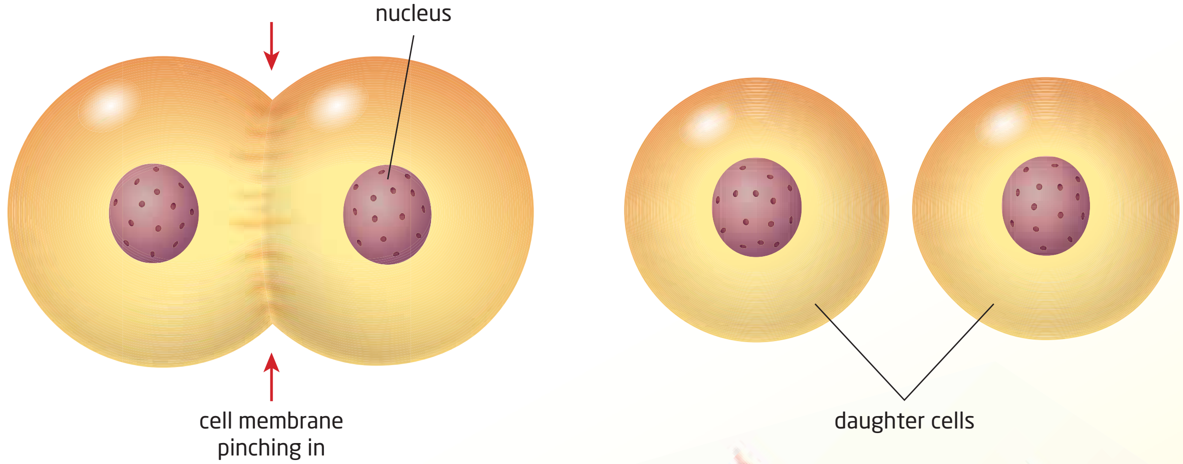
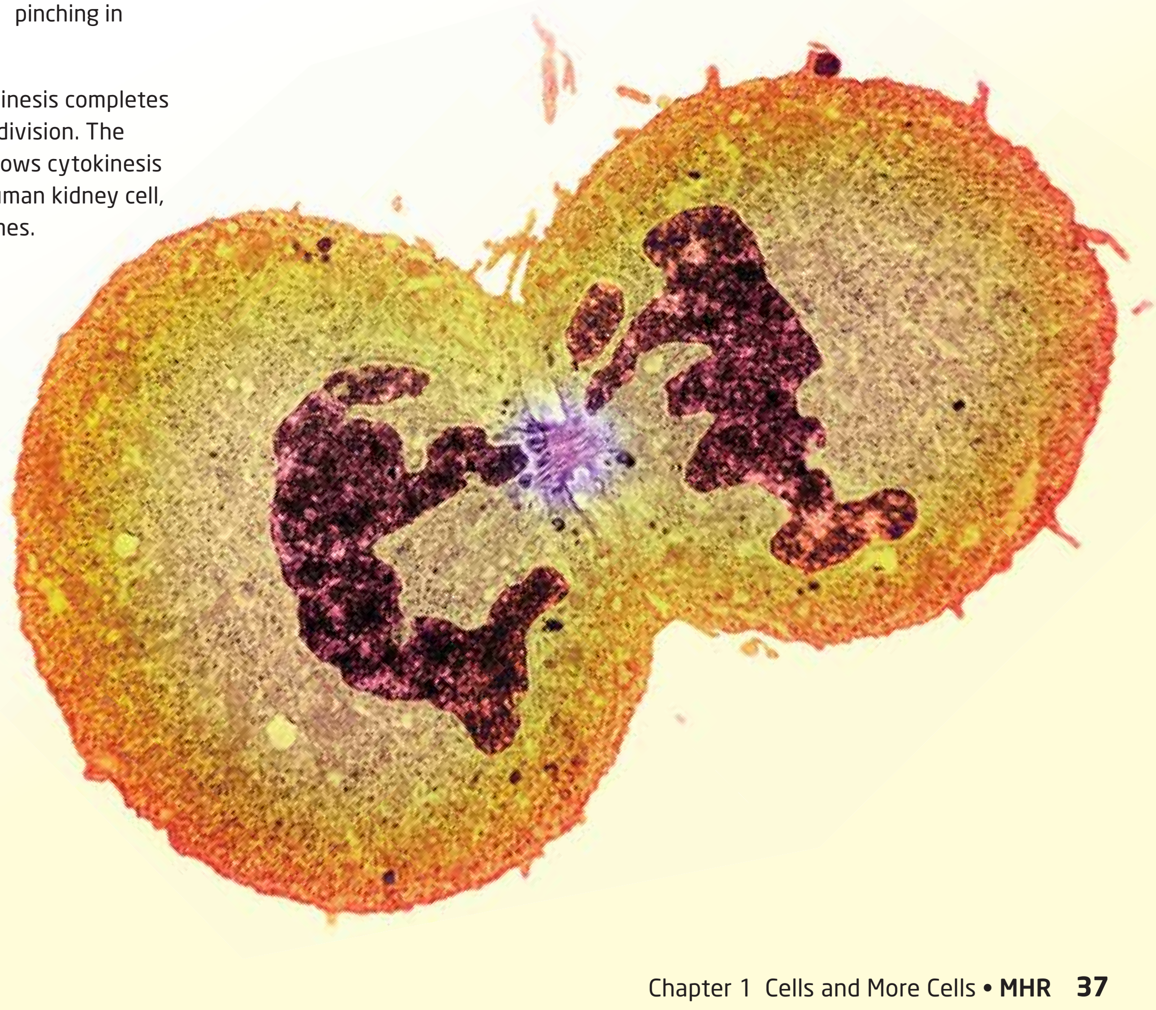


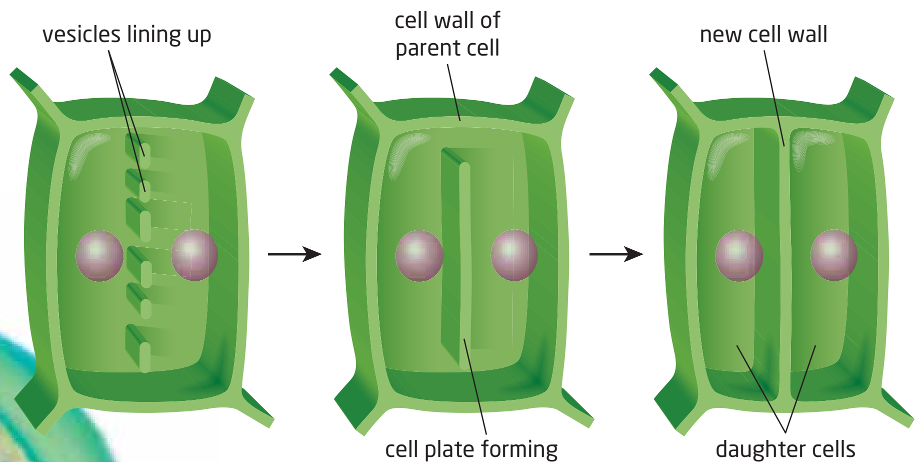
Figure 1.26 Cytokinesis completes the process of cell division. The micrograph here shows cytokinesis taking place in a human kidney cell, magnified 1800 times.



Cytokinesis in Plant Cells

The process of mitosis in plant cells is the same as in animal cells. However, in plant cells, the rigid cell wall makes it necessary for cytokinesis to be slightly different. In plant cells, the Golgi body starts to produce small vesicles. Each of these sacs carries the materials needed to form a new cell wall. The vesicles line up between the two new nuclei, forming a **cell plate**. The cell plate grows outward and joins the old cell wall. New cell walls are secreted on each side of the cell plate, dividing the cytoplasm into two. Then new cell membranes form inside the cell walls, and the division is complete.

cell plate a structure that that helps to form the cell wall in the process of plant cell cytokinesis



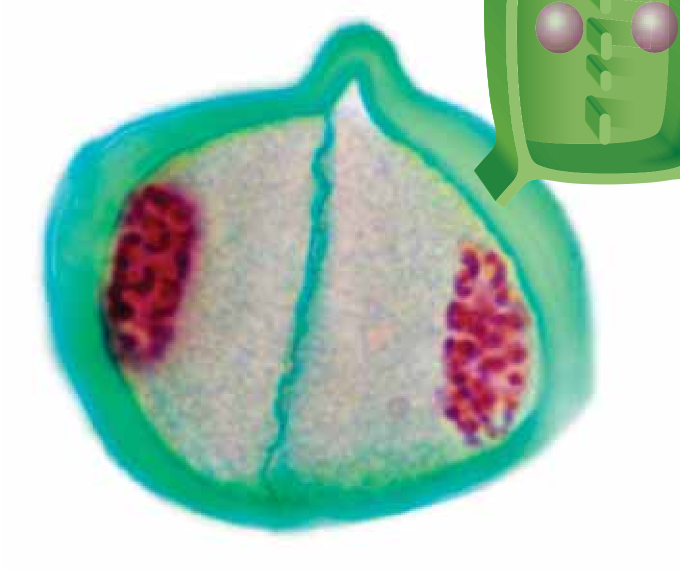


Figure 1.27 Cytokinesis in plant cells is slightly different from cytokinesis in animal cells because plant cells must form a new cell wall. In the micrograph on the left, you can see cytokinesis taking place in the cell of a lily, magnified 400 times.

The Same, but Different

You have seen that cell division produces two cells from one. Repeated over and over again, millions of times, this process allows you to grow from a single cell (after fertilization) into a multicellular fetus and finally into a full-sized human. The processes of DNA replication and mitosis ensure that each of your body cells has identical genes and can theoretically produce the same proteins.

Yet, you know that different cells have different structures and functions. Although all cells have the same basic set of internal structures, they make different proteins and contain different numbers of certain types of organelles. This happens as a result of cell specialization, a process you will learn more about in the next chapter. When cells specialize, they use only some of their genes—others are deactivated. In fact, most of the cells in your body use only about 10 percent of their genes to produce the proteins they need to do their particular job. So, although all of your body cells contain the same information, they do not all use it in the same way.

Section 1.3 Review

Section Summary

- When single-celled organisms and body cells of animals and plants divide, they form two identical daughter cells. For single-celled organisms, cell division results in population growth. For multicellular organisms, cell division allows individuals to grow or to replace lost or damaged cells.
- Cell division must be preceded by DNA replication so that each daughter cell gets the same DNA and genes as its parent cell.
- Cell division is a continuous process that involves two stages: mitosis, to divide the nucleus, and cytokinesis, to divide the cytoplasm.

Review Questions

K/U **1.** Give as many reasons why cells divide as you can.

K/U **2.** Compare prophase and telophase in mitosis.

C **3.** Create a graphic organizer to summarize the essential activities during each phase of mitosis. Go to Study Toolkit 4 to see possible organizers you might choose.

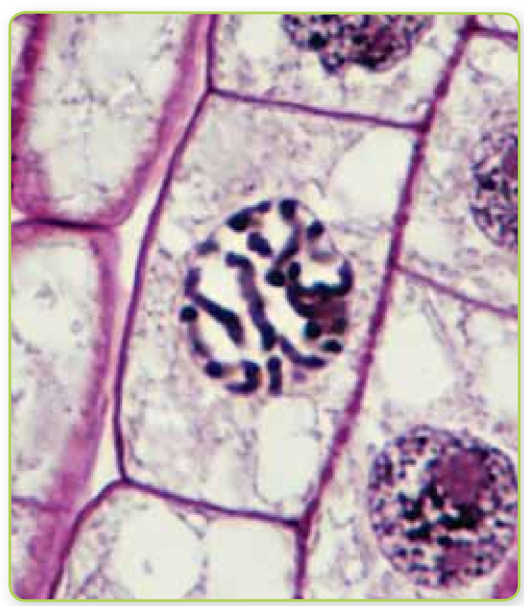
C **4.** How do the prefixes *pro*-, *meta*-, *ana*-, and *telo*- relate to what happens in each phase of mitosis? Look back to **Figure 1.25** for clues.

T/I **5.** If there are 10 chromosomes in a particular cell at the start of prophase, how many will be present in the same cell at the end of anaphase, before cytokinesis has begun? How many will there be after cytokinesis has occurred?

C **6.** Use diagrams to show the difference between cytokinesis in plants and animals.

K/U **7.** You have been given the micrograph on the right. Describe the cell structures you see and what this tells you about the cell.

A **8.** Biologists have noticed that within many groups of similar organisms, types that live farther north tend to be larger. For example, grey squirrels in Ontario and the northern United States are much larger than grey squirrels in the southern United States. Why do you think this might be?



Onion root tip, 500×